Weather and Hurricane Forecasts are Improved by Assimilating Precipitation from TRMM and GPM

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Outline

- **Methods to effectively assimilate precipitation** (*Lien et al. 2013*)
- **Applications**

  Global forecasts: **US GFS model/NASA TMPA** (*Lien et al.* 2016 a,b)

  Japan NICAM model/JAXA GSMaP (*Kotsuki et al*. 2016)

  TC predictions: **Japan SCALE model/JAXA GSMaP**

- **A universal QC algorithm for DA based on EFSO**

  Using NASA TMPA as an example (*Lien et al.* 2018)

Gaussian Transformation (Lien et al., 2013)

- Assimilation of precipitation fails to improve forecasts beyond a few hours. For example, the North American Regional Reanalysis (NARR): produced perfect rain, but forecasts did not improve.
- Two reasons:

  (1). Precipitation errors are not Gaussian

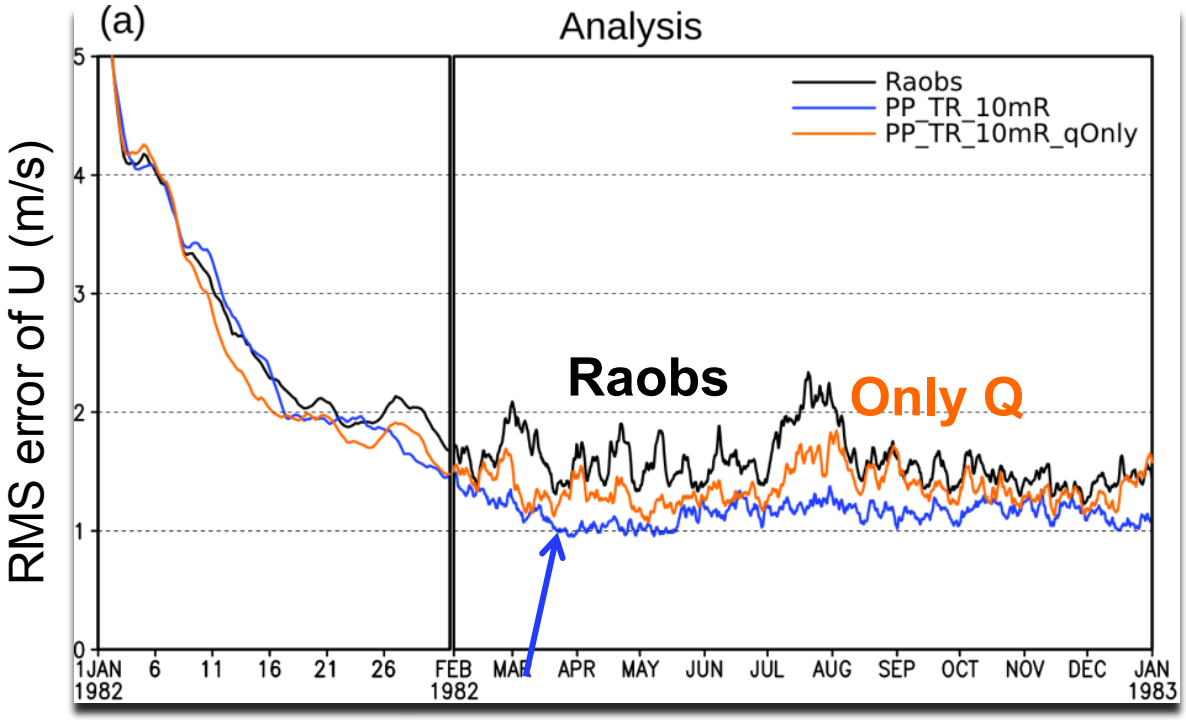
  (2). Changing moisture to force the model to rain as observed doesn't affect Potential Vorticity

***Lien et al.* (2013):**

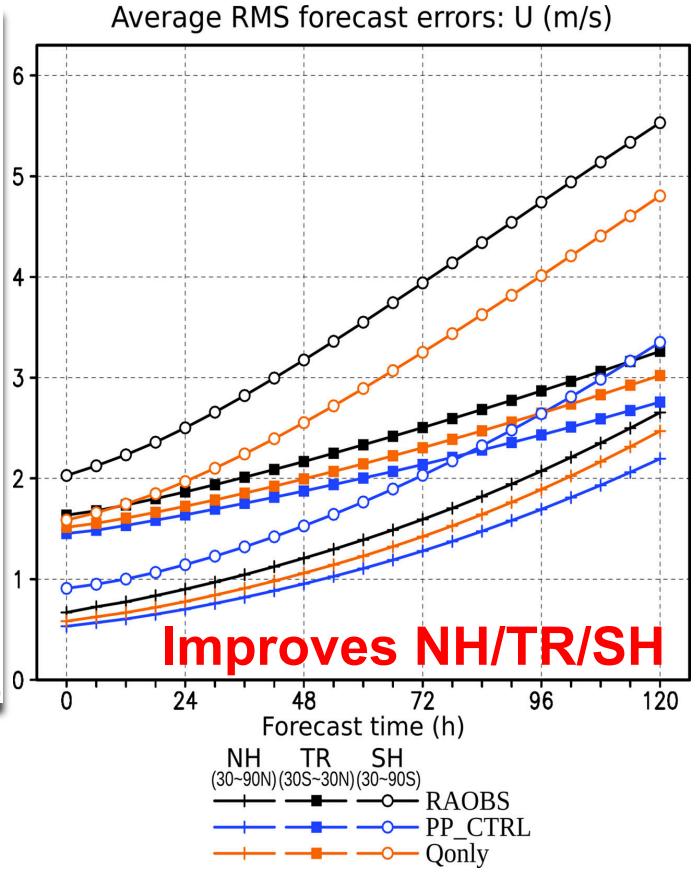
- A new approach deals with non-Gaussianity, by transforming precipitation into a Gaussian variable
- LETKF directly modifies Potential Vorticity by assigning more weights to the member with better dynamics

The model now "remembers" the assimilation, so that medium range forecasts are improved.

Perfect model simulation (Lien et al., 2013)



Gaussian, 10 members rain, 20% error, all variables



- **Results:** **For the first time the forecasts remembered the assimilation of precipitation and the 5-day forecasts are improved!**

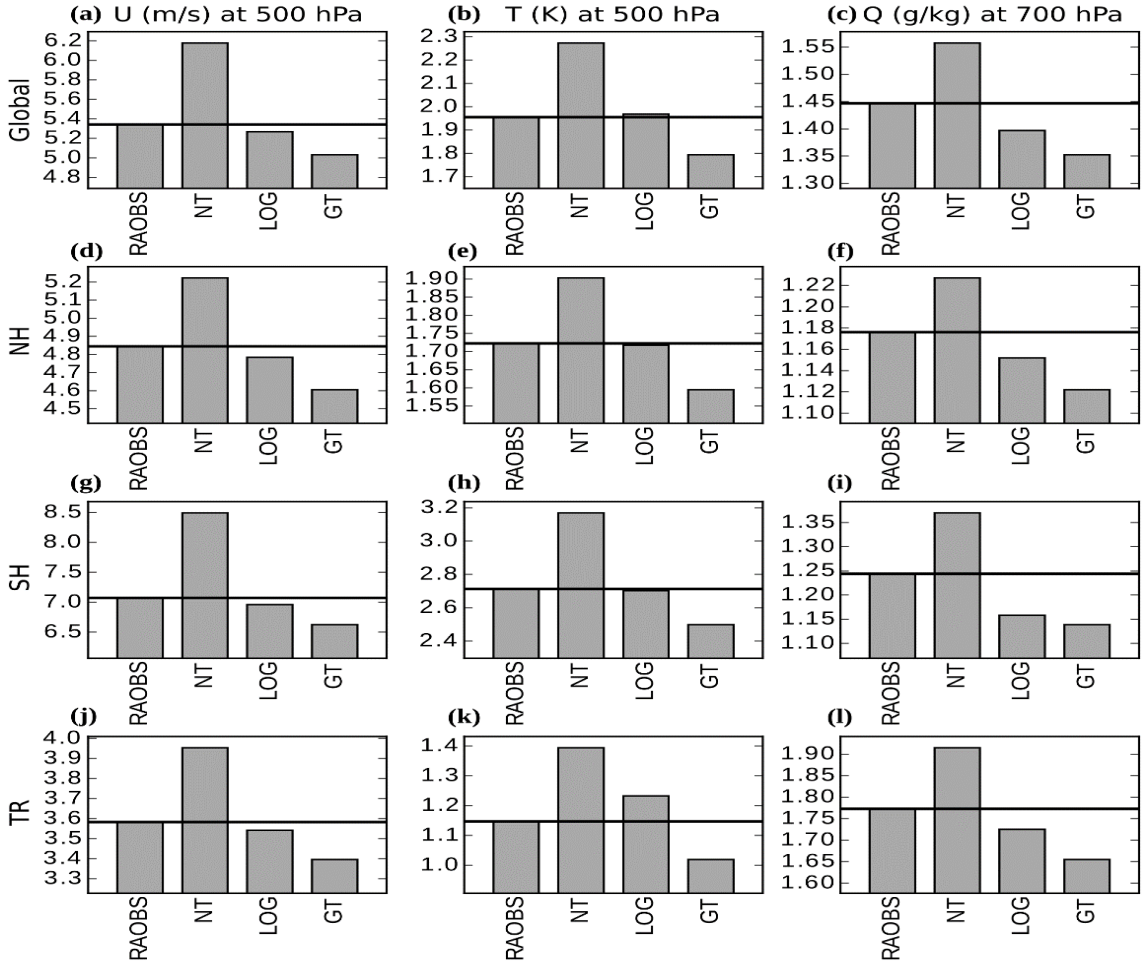
1. Assimilating TMPA in the GFS (Lien et al., 2016 a,b)

Results: Assimilating TRMM rain with a GFS T62 model verified against ERA Interim (RMSE)

Comparing RMSE of
RAOBS (no assim of pp, control)
Assim. with No Transform (NT)
Assim. with LOG Transform (LOG)
Assim. w Gaussian Transform (GT)

Gaussian Transform is the best in all areas, for all variables

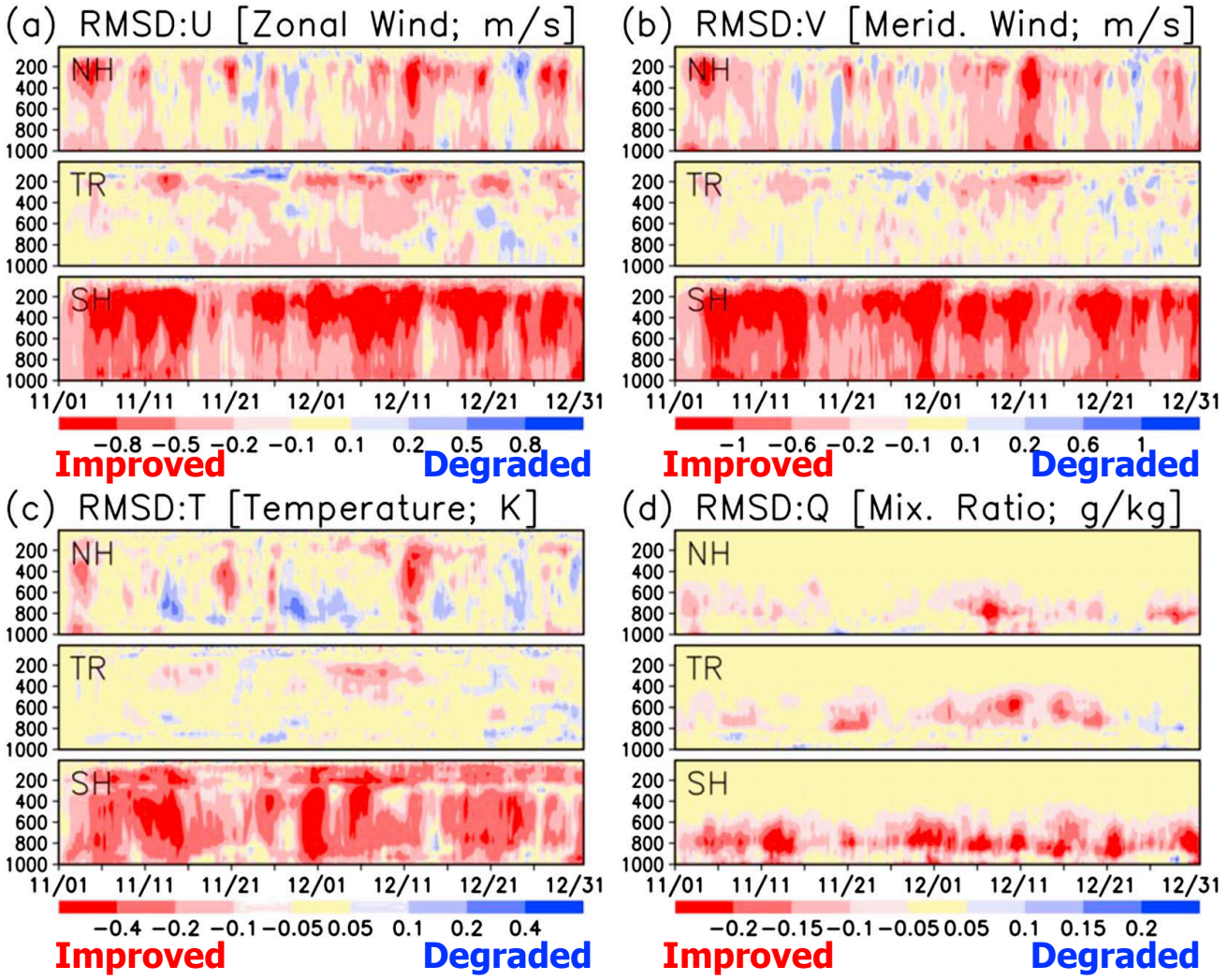
1-yr averaged 24hr forecast RMSE



2. Assimilating GSMaP in the NICAM (Kotsuki et al. 2016)

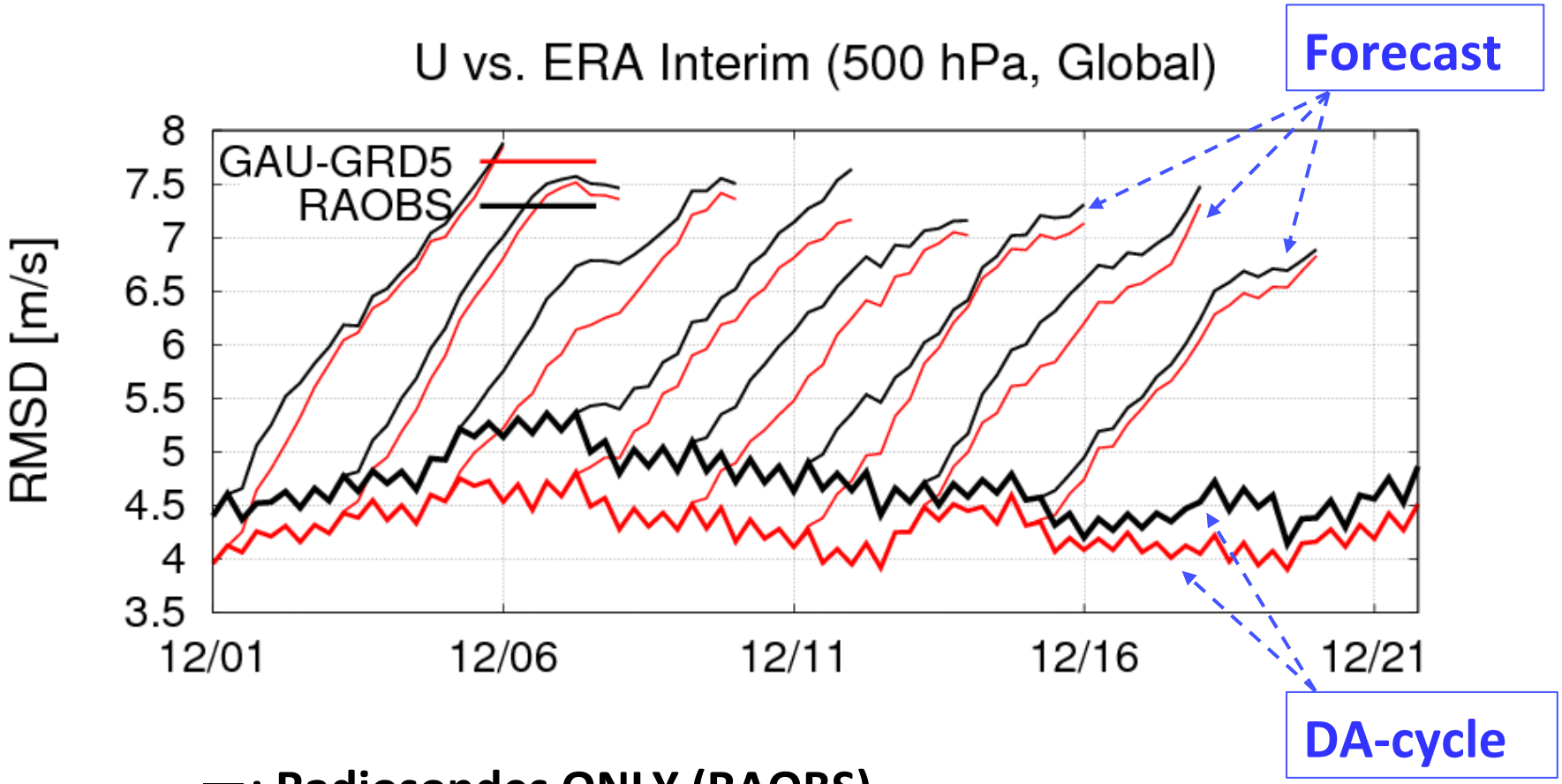
The GT method also works in the combination of Japan NICAM model and JAXA GSMaP retrievals. (Kotsuki et al. 2016)

difference of analysis RMSD relative to the ERA-Interim



2. Assimilating GSMaP in the NICAM (Kotsuki et al. 2016)

The 5-day U-wind forecast improves!



—: **Radiosondes ONLY (RAOBS)**

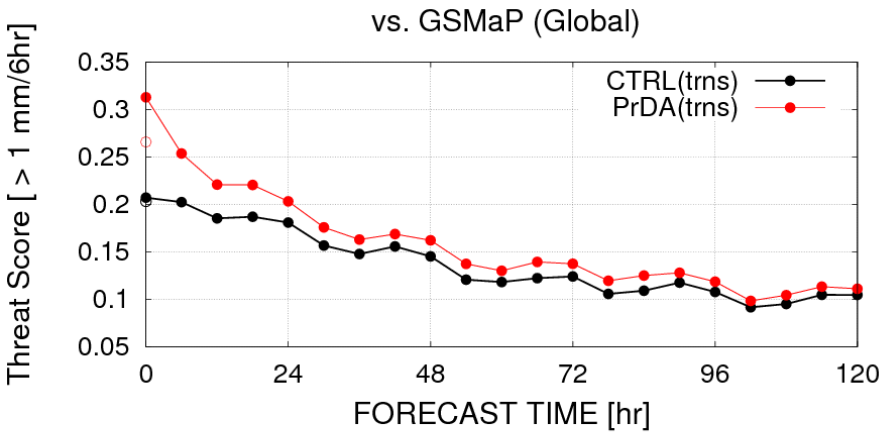
—: **Radiosondes + GSMaP/Gauge (GRD5)**

Validation with mean of ensemble forecasts from different initial dates

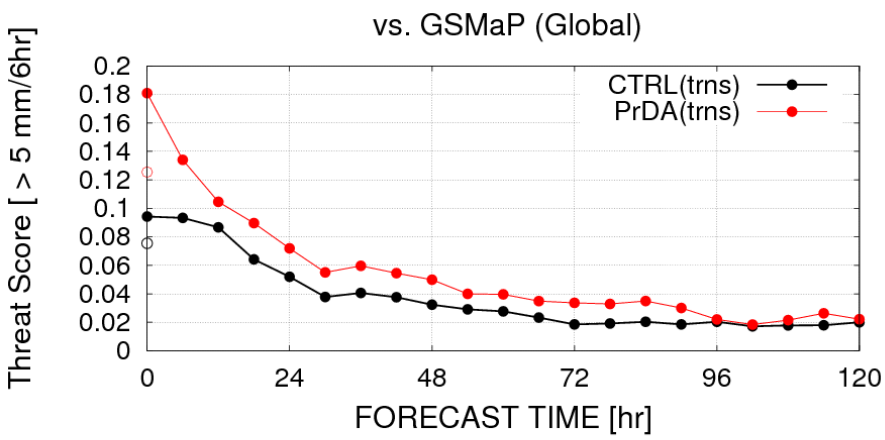
2. Assimilating GSMaP in the NICAM (Kotsuki et al. 2016)

The 5-day precipitation forecast also improves!

Threat Score (≥ 1 mm/6hr)



Threat Score (≥ 5 mm/6hr)



—: Radiosondes ONLY (RAOBS)

—: Radiosondes + GSMaP/Gauge (GRD5)

Precipitation forecasts are improved !

Average from different initial dates

3. TC predictions: Assimilating GSMaP in the SCALE

Cheng Da: he received a NASA NESSF 2018 scholarship!

Can the same methodology also improve hurricane forecasts?

Our Answer: YES!

- Because LETKF can effectively adjust the potential vorticity of hurricanes through assimilating precipitation brought by them.
- We verify this through assimilating JAXA GSMaP into the Japan mesoscale model SCALE.

3. TC predictions: Assimilating GSMaP in the SCALE

Adjustment of SLP

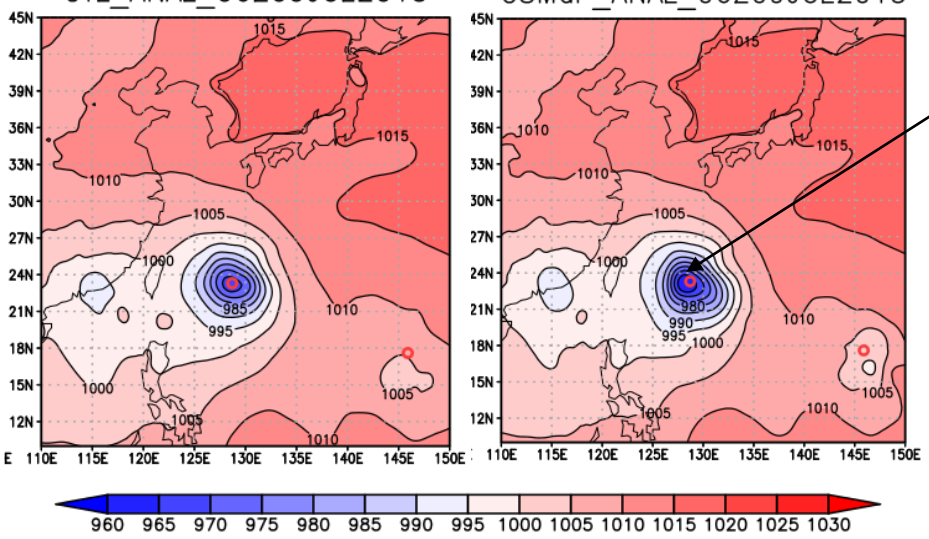
1st cycle

w/o GSMaP

CTL_ANAL_06Z09JUL2015

w/ GSMaP

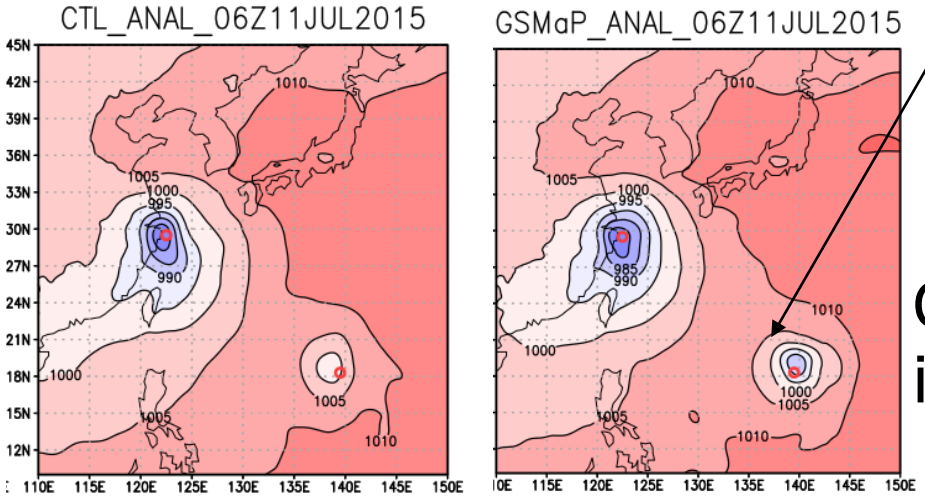
GSMaP_ANAL_06Z09JUL2015



9th cycle

CTL_ANAL_06Z11JUL2015

GSMaP_ANAL_06Z11JUL2015



CHAN-HOM

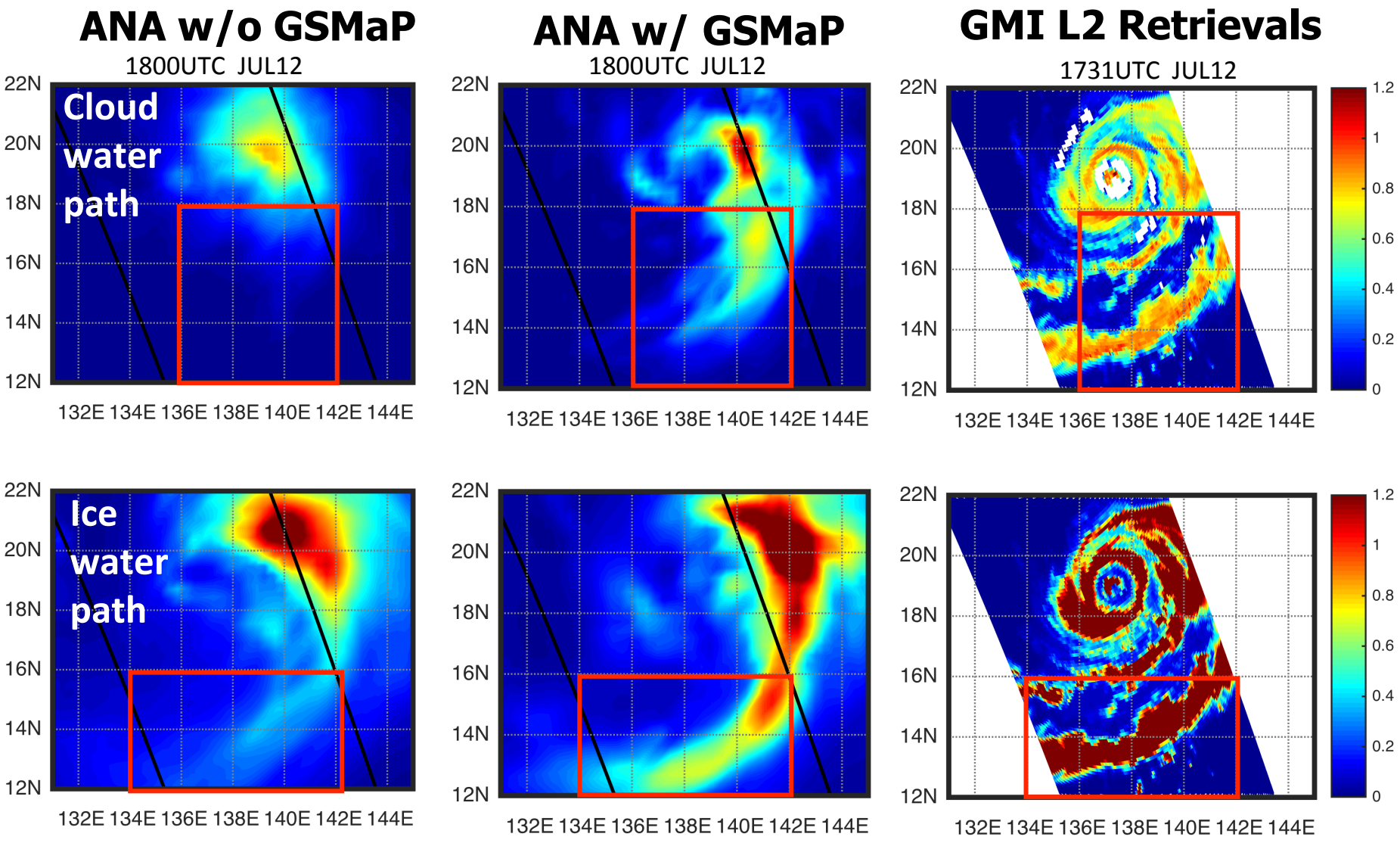
Source	Min. SLP (mb)
Background	973.8
w/o GSMaP	967.4
w/ GSMaP	**960.2**
JMA Best Track	**960**

NANGKA

Source	Min. SLP (mb)
CTL_ANA	997.8
GSMaP_ANA	985.7
JMA Best Track	945

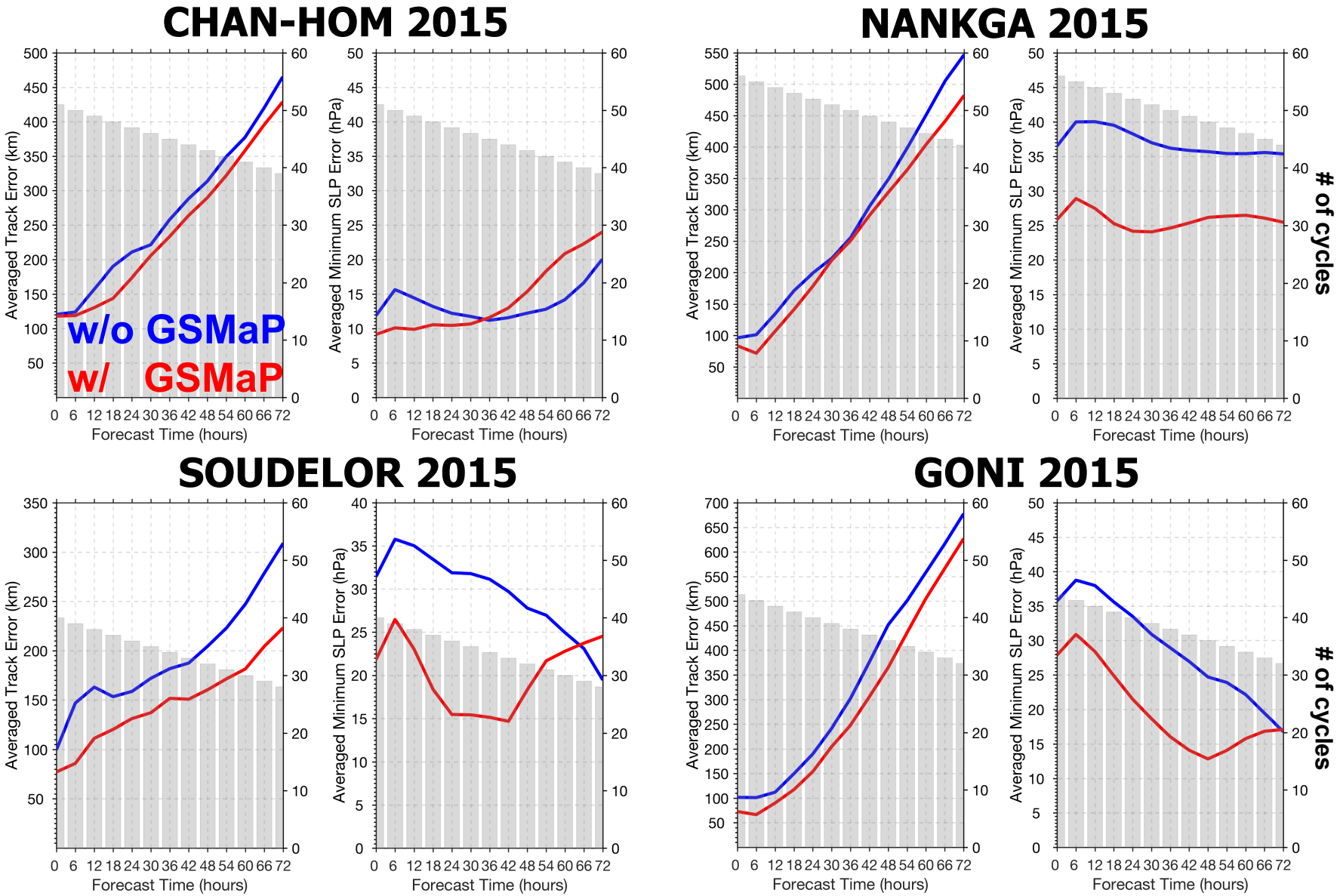
GSMaP assimilation effectively intensifies the SLP.

3. TC predictions: Assimilating GSMaP in the SCALE



GSMaP assimilation adjusts the hydrometeor fields.

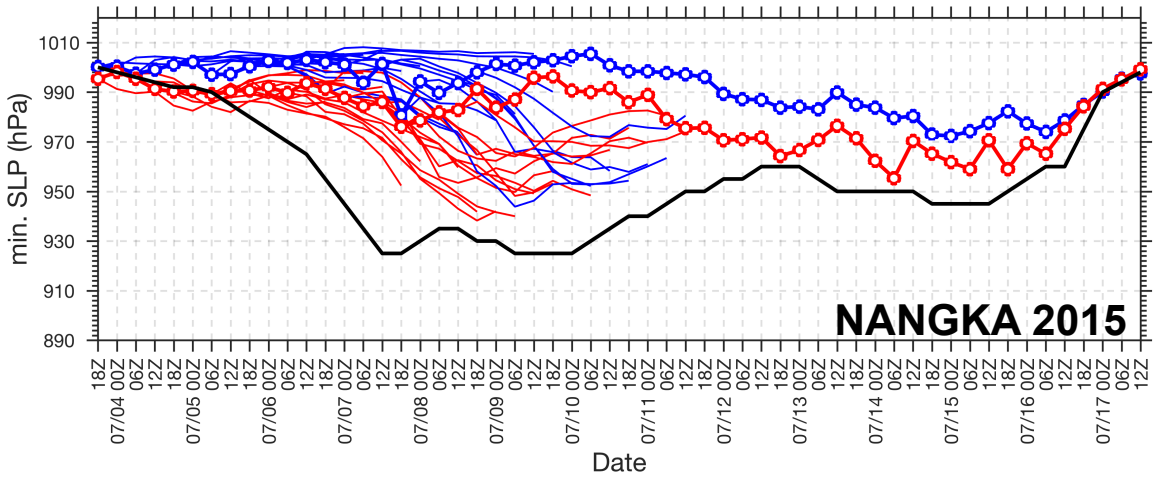
3. TC predictions: Assimilating GSMaP in the SCALE

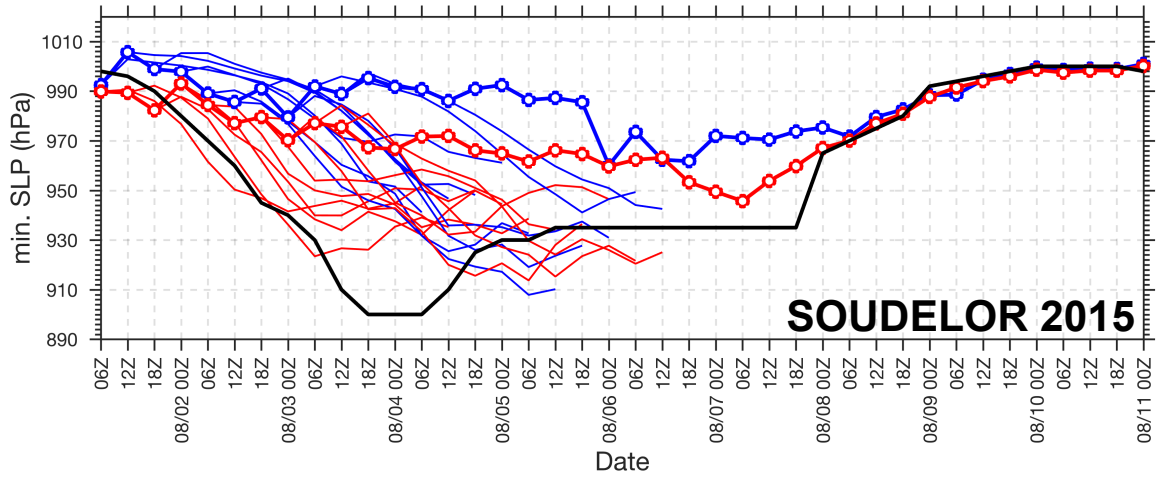


Assimilating GSMaP improves 3-day track and intensity forecast of 4 typhoons in 2015.

3. TC predictions: Assimilating GSMaP in the SCALE

3-day MSLP Forecast Initialized at Different Times





w/o GSMaP
w/ GSMaP
JMA best track

Assimilating GSMaP is especially beneficial during the early stage of the TC development.

A Universal QC algorithm based on EFSO (Lien et al., 2018)

Kalnay et al. 2012, proposed ensemble forecast sensitivity to observations (EFSO).

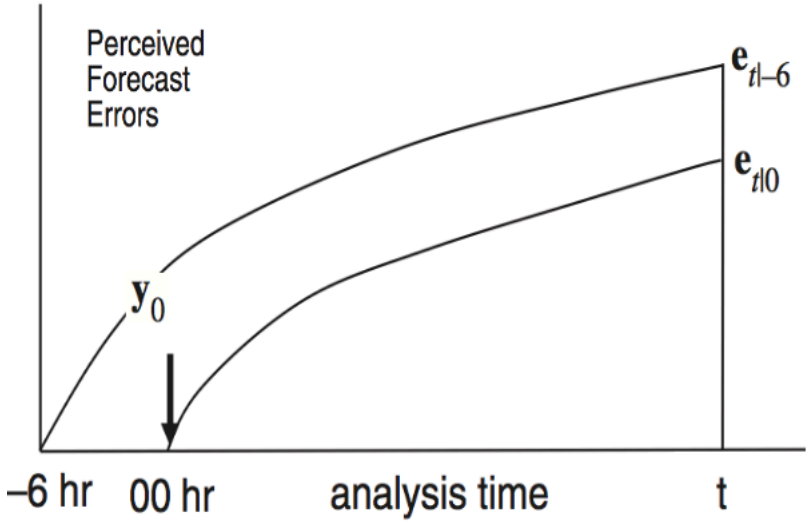
Low cost: terms already computed by the EnKF

$$\Delta e^2 = \mathbf{e}_{t|0}^T C \mathbf{e}_{t|0} - \mathbf{e}_{t|-6}^T C \mathbf{e}_{t|-6}$$
$$\approx \frac{1}{K-1} \delta \mathbf{y}_0^T \mathbf{R}^{-1} \mathbf{Y}_0^a \mathbf{X}_{t|0}^{fT} C (\mathbf{e}_{t|0} + \mathbf{e}_{t|-6})$$

O-B of the ens. mean

Analysis perturbation in obs. space

Forecast perturbation

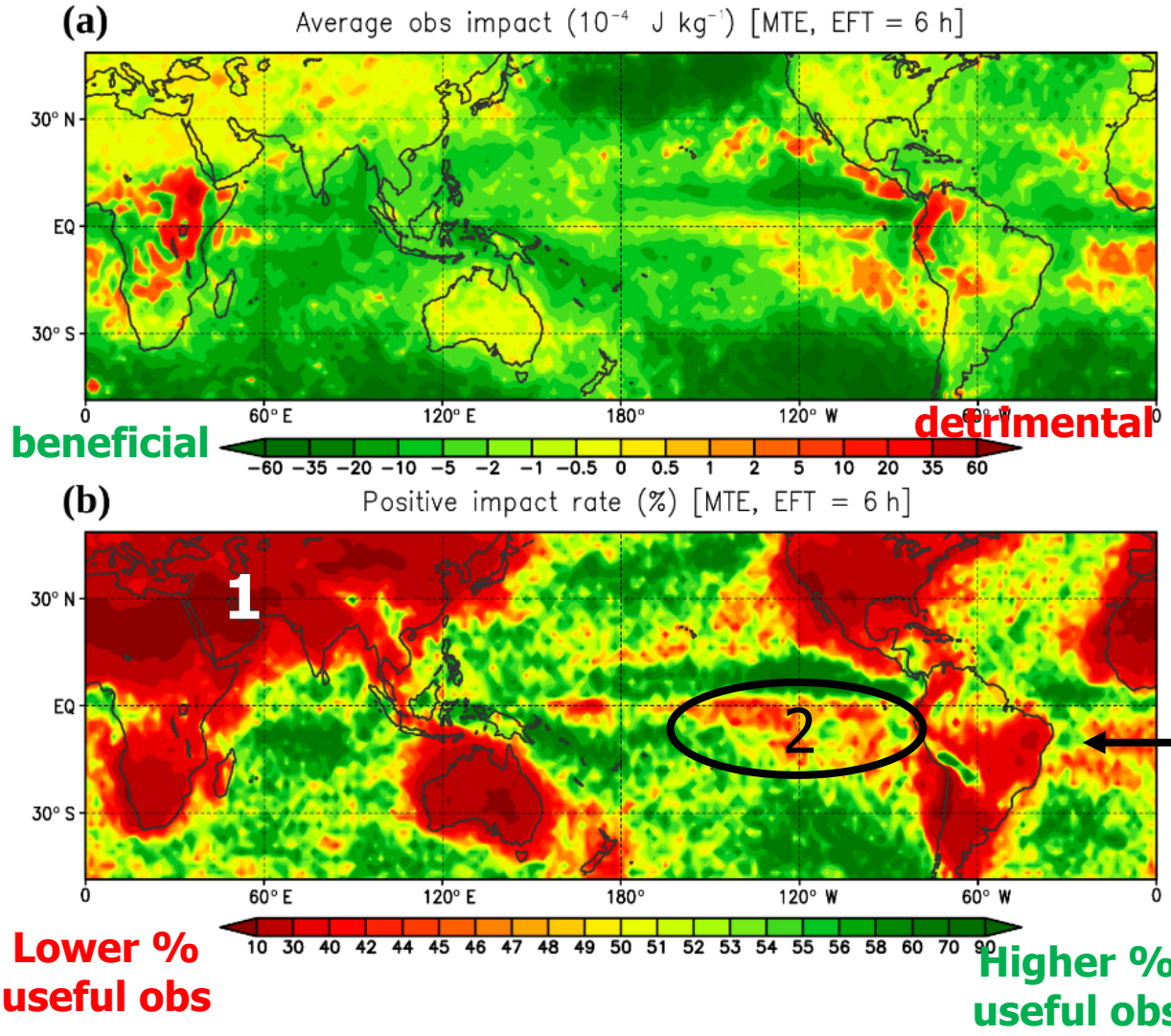


- EFSO quantifies how much each obs improves or degrades model forecasts.
- Negative EFSO means beneficial obs, while positive EFSO means detrimental obs.
- EFSO can be used **online** as Proactive QC (Chen et al., 2018).

- EFSO can also be used **offline** to guide QC design: TMPA is an example (Lien et al., 2018)

A Universal QC algorithm based on EFSO (Lien et al., 2018)

EFSO of TMPA retrievals



EFSO is consistent with our experience of model and retrieval deficiency:

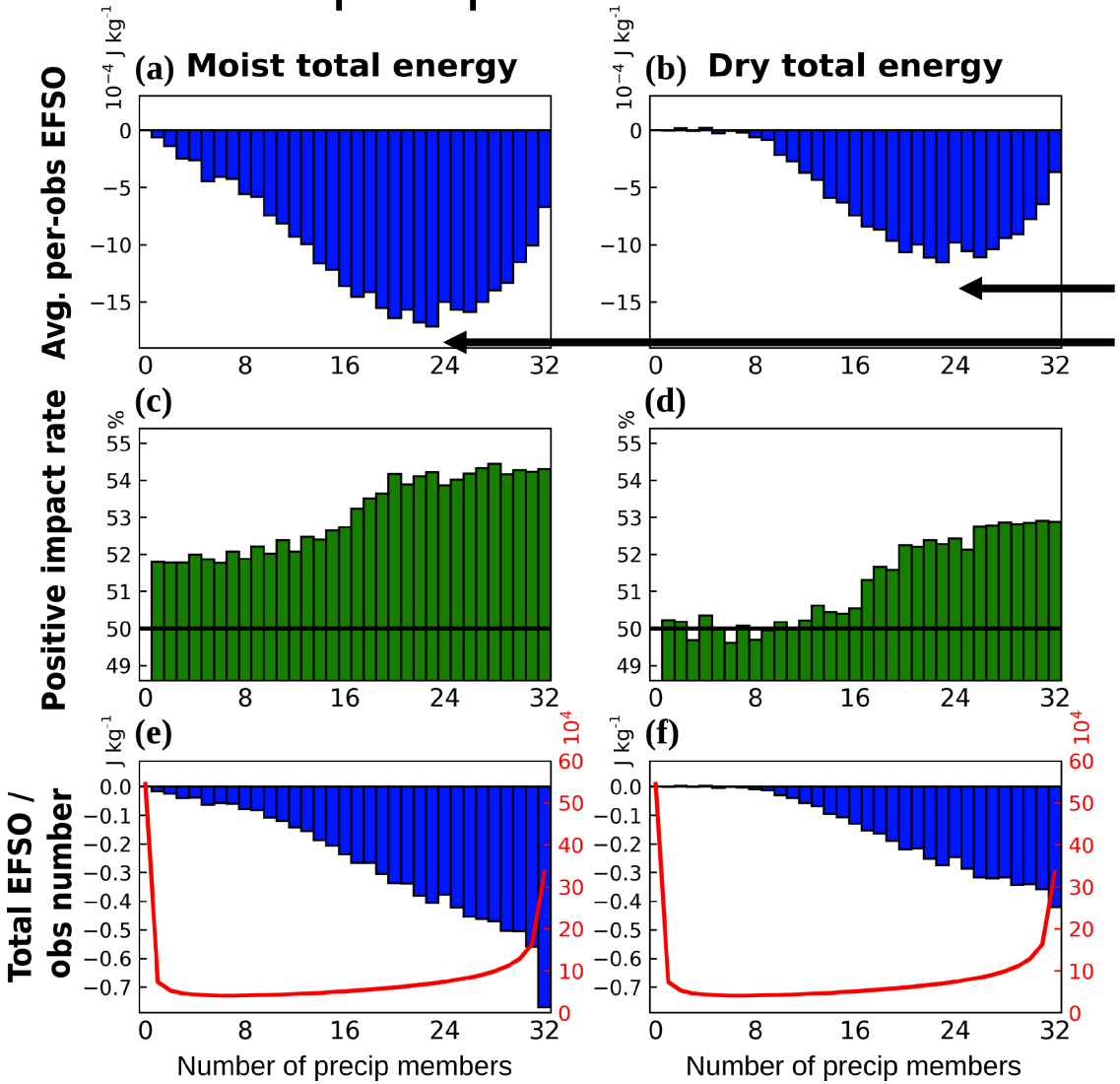
1. Retrievals over land are of poorer quality than those over ocean

2. Model tends to incorrectly precipitate too often west of the continents..

A Universal QC algorithm based on EFSO (Lien et al., 2018)

EFSO tells us other useful information:

1. How does EFSO depend on the number of background ensembles that precipitate?



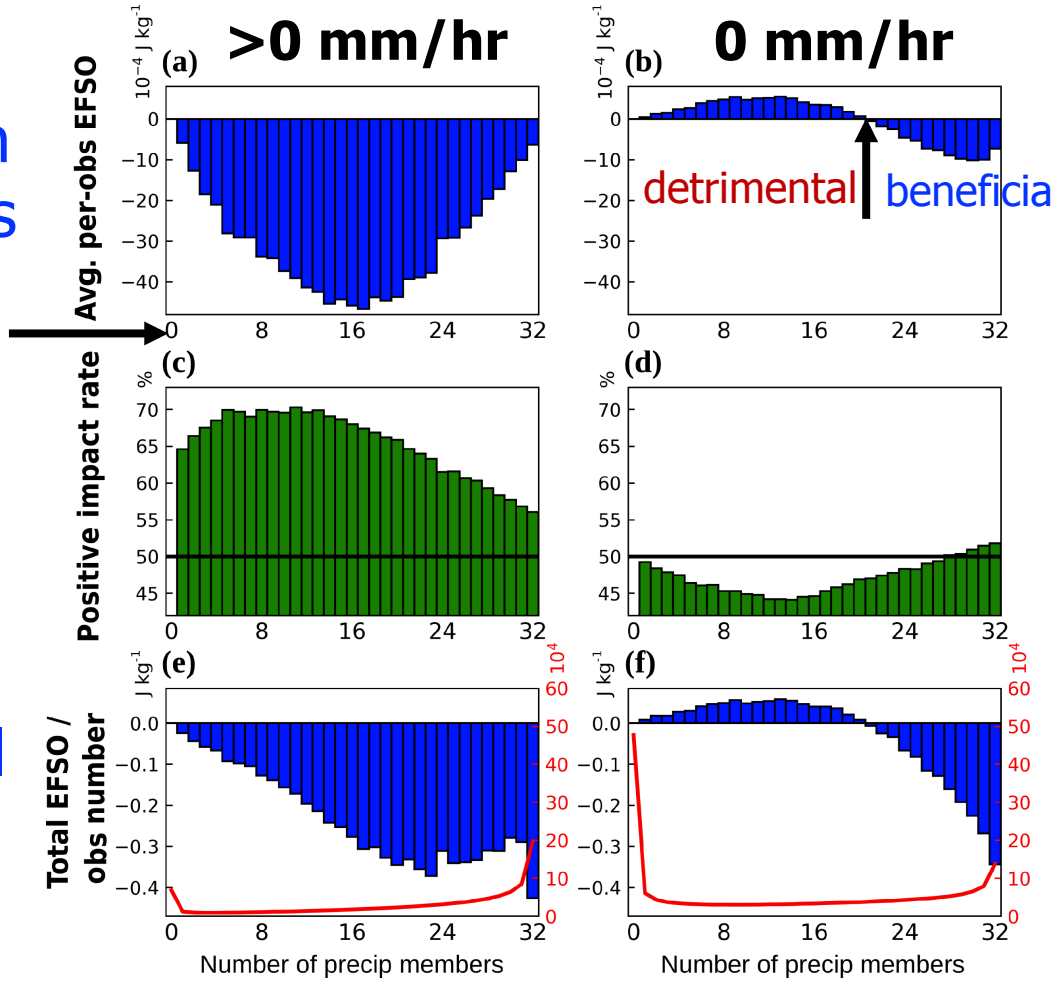
obs is most beneficial when **24** members precipitates.

A Universal QC algorithm based on EFSO (Lien et al., 2018)

EFSO tells us other useful information:

2. any dependence of EFSO on the retrieved precipitation amount?

Precipitation >0 is always beneficial (EFSO<0). The more it rains, the more beneficial. Hence it will improve hurricane prediction.

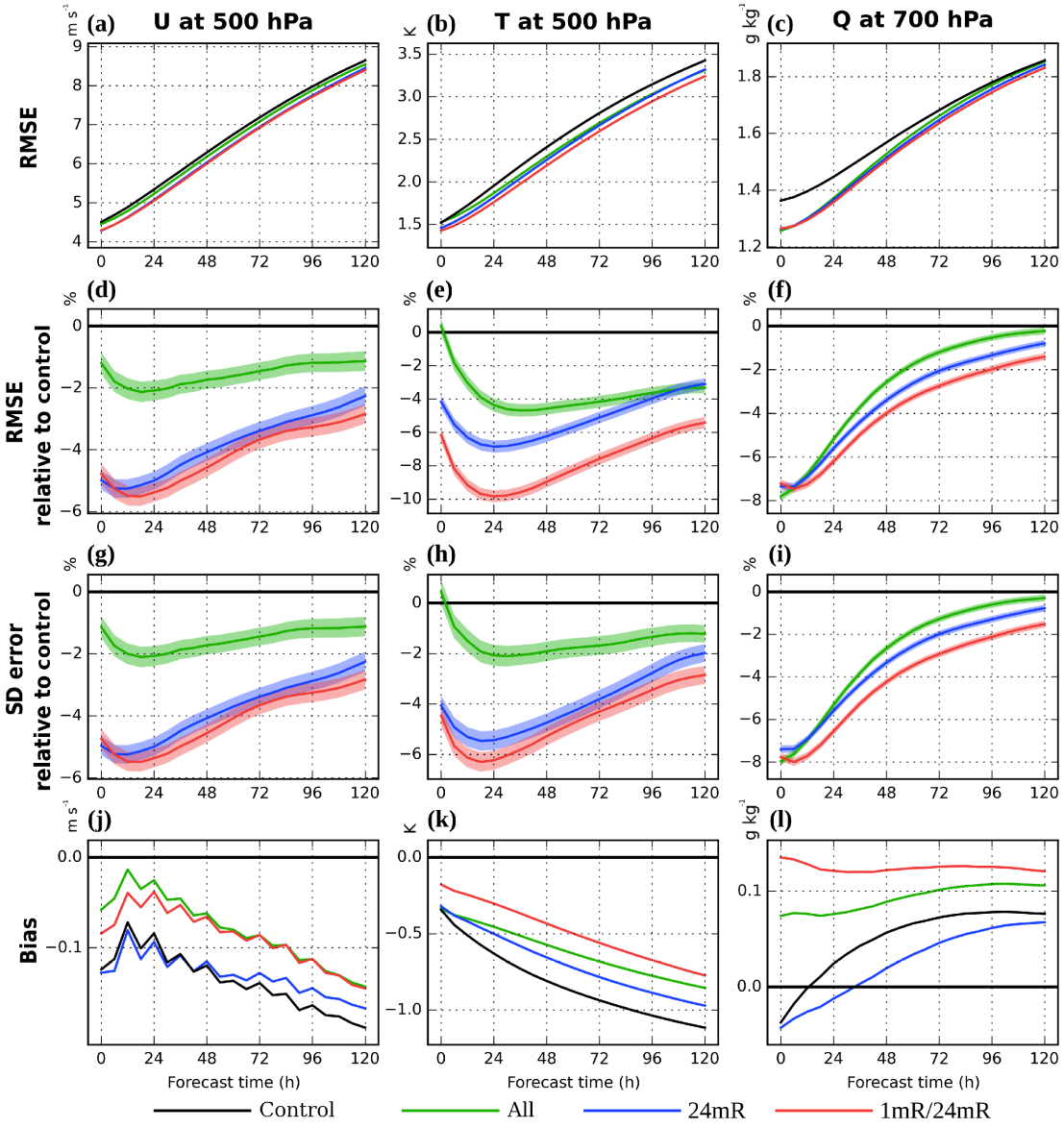


However, it is difficult for zero precipitation to be beneficial. Only if many ensemble members wrongly precipitate, it is beneficial.

A Universal QC algorithm based on EFSO (Lien et al., 2018)

Run the experiment with additional QC based on EFSO:

5-day forecast RMSE relative to ERA-Interim



Control: No additional QC

All: assimilate TMPA when all members precipitate

24mR: assimilate TMPA when 24 members precipitate

1mR/24mR: assimilate TMPA>0 when at least 1 member rains, and zero TMPA when 24 members precipitate

Experiments with EFSO-guided QC give better results!

Summary

- We developed a method to assimilate non-Gaussian-error observations, and apply it to assimilate precipitation.
- Results show that assimilating NASA TMPA or JAXA GSMaP with Gaussian Transformation in the ensemble data assimilation system improves global 5-day forecasts, and TC predictions.
- We developed a universal QC algorithm based on EFSO to accelerate new observing systems. Applying additional QC based on EFSO, further improves the forecasts.
- We will further advance the assimilation of the NASA IMERG and JAXA GSMaP through our NASA NESSF project:

  (1) TC predictions: Implement EFSO in the Japan SCALE model and improve the assimilation of over-land IMERG/GSMaP

  (2) Global forecasts: Investigate the IMERG/GSMaP impact with a denser observation network (PrepBUFR+AMSUA) and EFSO.